Development a fuzzy system for change prediction in construction projects

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Summary

Change management has been the focus of different IT systems. These IT systems were developed to represent design information, record design rationale, facilitate design co-ordination and changes. They are largely based on managing reactive changes, particularly design changes, in which changes are recorded and then propagated to the relevant project members. However, proactive changes are hardly dealt with in IT systems. Proactive changes require estimating the likelihood of occurrence of a change event as well as estimating the degree of change impacts on project parameters. Changes in construction projects often result from the uncertainty associated with the imprecise and vague knowledge of much project information at the early stages of projects. This is a major outcome of the case studies carried out as part of this research. Therefore, the proposed model considers that incomplete knowledge and certain project characteristics are always behind change causes. For proactive changes, predicting a change event is the main task for modelling. The prediction model should strive to integrate these main elements: 1) project characteristics that lead to change 2) causes of change, 3) the likelihood of change occurrence, and 4) the change consequences. It should also define the dependency relationships between these elements. However, limited data (documented) are only available from previous projects for change cases and many of the above elements can only be expressed in linguistic terms. This means that the model will simulate the uncertainty and subjectivity associated with these sets of elements. Therefore, a fuzzy model is proposed in this research to capture these elements. The model analyses the impact of each set of elements on the other by assigning fuzzy values for these elements that express the uncertainty and subjectivity of their impact. The main aim is to predict change events and evaluate change effects on project parameters. The fuzzy model described above was developed in an IT system for operational purposes and was designed as a Java package of components with their supporting classes, beans, and files. This paper describes the development and the architecture of the proposed IT system to achieve these requirements. The system is intended to help project teams in dealing with change causes and then the change consequences in construction projects.

1 Introduction

Changes in construction projects are common, likely and not often immediately well-defined, but time has to be taken by the project team to consider the full information of changes. Therefore, the issue of managing change has grown in importance. Change management relates all project internal and external factors that influence project changes. Research projects on managing change in construction have tended to focus on the identification of factors affecting the success of a change process, and to introduce guidance for best practice of change implementation. Examples of such research include: a concept for project change management (Construction Industry Institute CII 1994), best practices for managing change efficiently (CII conference 1996), a generic procedure for issuing a change order request (Cox et al 1999), an analysis method to reduce the overall rate of construction change orders (Stocks and Singh 1999), a best practice guide to present best practice recommendations for the effective management of change on projects (Construction Industry Research and Information Association CIRIA 2001), and an advanced project change management system (Ibbs et al 2001).

Several other researchers have investigated the evaluation of change effects on certain project elements. Hester et al (1991) studied construction change order impacts on labour productivity at the craft level. Ibbs (1997) investigated the effect of the size and the time of change on a project. Hanna et al (1999) developed a linear regression model that predicts the impact of change orders on labour productivity. Williams (2000) studied the risk of changes to safety regulations and its effect on a project.

The above literature on change management and evaluation mainly focused either on the identification of the change process, best practice recommendations for managing change during the project life cycle, or evaluation of the change effects on a single project parameter. Identification and recommendation alone are not enough to help in managing change effectively, as change management should help in forecasting possible changes, planning impact control strategies/measures, and coordinating changes across the entire project. On the other hand, evaluation of change effects without relating multiple change causes to multiple change effects (which is the case for many change events) does not consider the whole case of change.

Change management has also been the focus of different IT systems. An integrated environment for computer-aided engineering was developed by Ahmed et al (1992), which is a blackboard representation that integrates a global database, several knowledge modules, and a control mechanism to systemize object changes. Peltonen et al (1993) proposed an engineering document management system for changes that incorporated document approval and release procedures. Spooner and Hardwick (1993) developed a system with rules for coordinating concurrent changes and for identifying and resolving conflict modifications. Ganeshan et al (1994) developed a system to capture the history of the design process, initiate backtracking, and determine the decisions that might be affected when changes are made in the spatial design of residential buildings. Krishnamurthy and Law (1995) presented an interesting change management model that supports multidisciplinary collaborative design environments. Another change management system was proposed by Mokhtar et al (1998) for managing design change in a collaborative environment. The model is capable of propagating design changes and tracking past changes. Soh and Wang (2000) proposed a constraint methodology based on a parametric technique to coordinate design consistency between different geometric models and to facilitate managing design changes. Hegazy et al (2001) introduced an information model to facilitate design coordination and management of design changes. Important dependencies between building components were represented by this model to help identify the ripple effect of changes between components. Also, a reporting system was used to view the history of all changes made by all disciplines. A more generic IT system was presented by Karim and Adeli (1999) which is an object-oriented (OO) information model for construction scheduling, cost optimisation, and change order management. Charoenngam et al (2003) developed a web-based change order management system that supports documentation practice, communication and integration between different team members in the change order workflow.

The above IT systems for change management were developed to be integrated systems that represent design information, record design rationale, facilitate design co-ordination and changes, and notify users of file changes. These systems were developed mainly to deal with reactive changes, particularly design changes.

Appropriate strategies for managing change can only be formulated when a change is thoroughly evaluated. The evaluation of construction change should strive to establish these main elements: 1) project characteristics that lead to change 2) causes of change, 3) the likelihood of change occurrence, and 4) the change consequences. It should also define the dependency relationships between these elements.

This research fouces on identifying and forecasting potential changes and developing solutions before the change occurs. This paper introduces a fuzzy model for predicting change events based on the available information at the early stages of a project and presents the IT system architecture of the proposed model. In the following sections, a brief introduction is given of the modelling approach before a detailed description of the system architecture.

2 Modelling change prediction

The amount and precision of information available at the early stages of a project often influence the number of change cases. This is a main outcome concluded from the case studies carried out as part of this research. Therefore, the proposed model assumes that incomplete knowledge and certain project characteristics are the main sources of changes. The proposed model simulates the cause and effect relationships within change cases, taking these project characteristics into consideration. The model takes the effect of project characteristics, that lead to change, into account. Furthermore, the likelihood of occurrence of change causes and effects that reflect the uncertainty around change occurrence will also be considered. Project characteristics (F_i) are factors or aspects that have an influence on the project and may lead to change. These characteristics can be defined at the early stages of projects. The other components of the relationship include the change causes and effects. Change causes (C_j) are the direct causes of a specific change event when it occurs; these are likely to be because of the existence of certain project characteristics. Change effects (E_k) are the change consequences on project parameters. Two measures, $\mathbf{R_{ij}}$ and $\mathbf{R_{jk}}$, have been used to represent the degree of dependency between F_i 's and C_j 's and between C_j 's and E_k 's, respectively. They actually represent the sensitivity of the impact of one set of elements to variations in another set of elements. Further details of the model elements (F_i, C_j and E_k) are set out elsewhere (Motawa et al 2003).

The model assumes that for every change case, there is a set of F_i , C_j and E_k elements that represents that specific case. The model attempts to predict change impacts on project parameters using data that are realistic to obtain, while limited data (documented) are only available from previous projects and many of the above elements can only be expressed in linguistic terms. This means that the model will simulate uncertainty and subjectivity of the impact and variations of these sets of elements. Therefore, a fuzzy model has been developed to relate these elements. Figure 1 illustrates the structure of the cause and effect relationships using three project characteristics, three change causes effect on a project parameter. Figure 1 can be used to analyze the relationship between the prediction elements in case of several project parameters. The model analyses the impact of each set of elements on the other by assigning fuzzy values to these elements. These fuzzy values are represented as follows:

F_i = the degree of influence of project characteristics on a specific project

C_j = the extent of a cause impact

R_{ij} = the sensitivity of a change cause occurrence to variations in the project characteristics

R_{jk} = the sensitivity of the change impact to variations in the change causes

R_{ij} & R_{jk} = 1.0 fully sensitive (strong impact)

0.0 < partially sensitive < 1.0

0.0 non-sensitive = no dependency exists

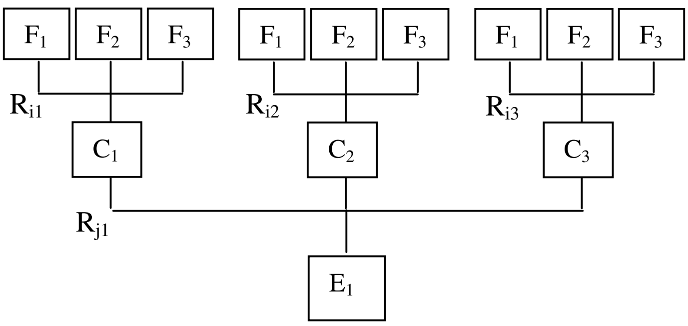

Figure 1. Analysis of cause-and-effect relationships for a change case

The analysis is undertaken for the expected change effects, considering all causes of change under specific project characteristics. Testing the sensitivity of the likelihood of change occurrence and the effects of change on project parameters due to variations in these sets of elements, is useful in alerting the project manager to changes so as to take corrective action and to minimise the disruptive effect of changes. A formula to execute this testing is developed by Motawa et al (2003).

3 IT system for the Fuzzy model

The fuzzy model described above was developed in an IT system for operational purposes. The system is designed as a Java package of components with their supporting classes, beans, and files. Figure 2 shows the architecture of the system and the relationships between its various components. Briefly, the main elements of the system are:

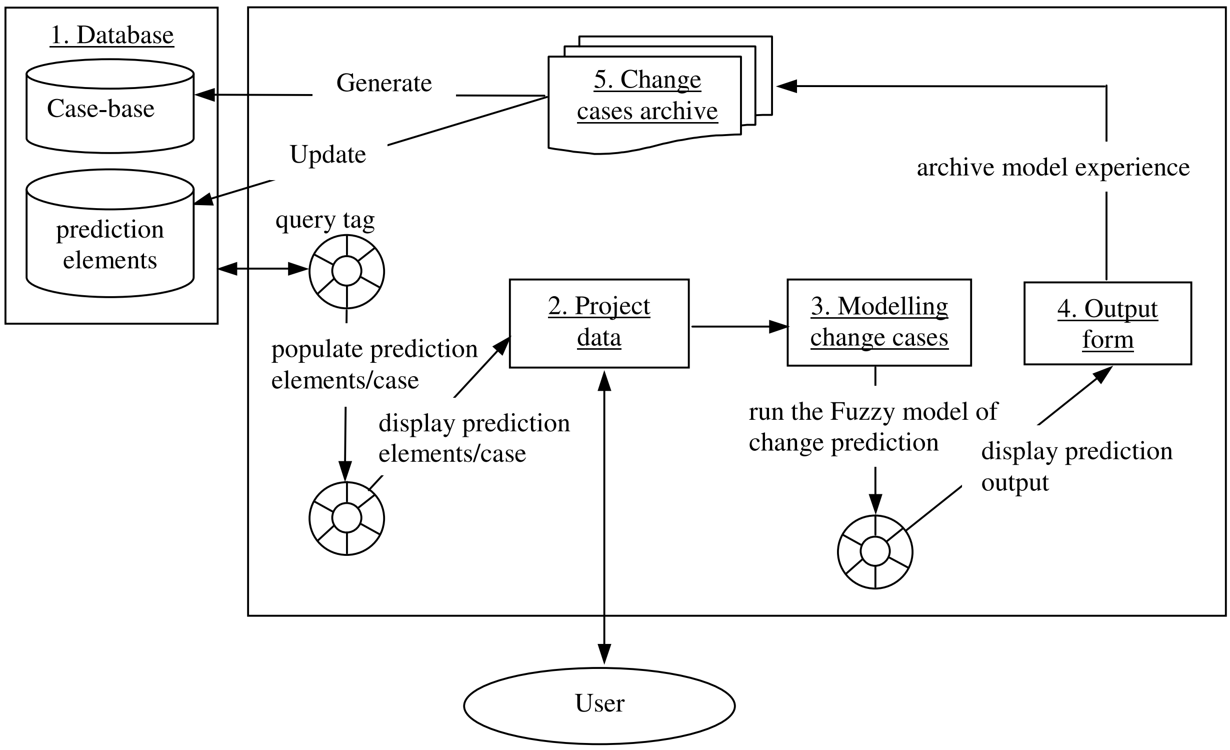

Figure 2. Architecture of the Change Prediction System

1. Database: The system efficiency depends on the quality of a well-designed information database. The system database contains two kinds of information: (1) data collected from the case studies carried out by this research project regarding the prediction elements of change, namely project characteristics, change causes and change effects. Tables were designed to store the required information for this database as well as the system outputs; and (2) case-based database. This represents specific knowledge tied to specific situations of a change case, also represents knowledge at an operational level; that is, how a change case was carried out or how a piece of knowledge was applied or what particular strategies for accomplishing a change case were used. Each case in the case base is composed of three major parts: change case description, system outcome and actual case scenarios. The description specifies the situation in a change case (i.e. the means by which the case was affected). The outcome indicates the analysis of the fuzzy results after the change case is modelled. The actual case scenario outlines any elements that have not been taken into account for modelling and have significant effect on the change case.

2. Project data: these are interface frames "JFC (Swing) Frames" (Java Foundation Class) that provide users with interactive tools. They are used to locate the input data which are selected from the database and/or entered directly by the user.

3. Modelling change cases: this is a Java code that translates the fuzzy model for change prediction and effects into computer program. The system allows both numerical and linguistic estimation for each element value.

4. Output form: it is a JFC Frame that displays the system outputs.

5. The archive is a documentation system for all information on the change case and the system output.

A set of links and buttons has been designed to navigate from page to page and to run the system's functions.

4 Information flow within the system

The system consists of three functions: (1) change case identification, (2) prediction of likelihood of change occurrence and effects, and (3) case base archiving. These functions are interconnected within the system. Figure 3 represents the conceptual information flow model and the interaction between the system functions. The rectangles in Figure 3 represent function activity boxes, labeled-arrows represent data required to achieve a function, and arrows that link boxes show information & logic flow, and relationships between the functions.

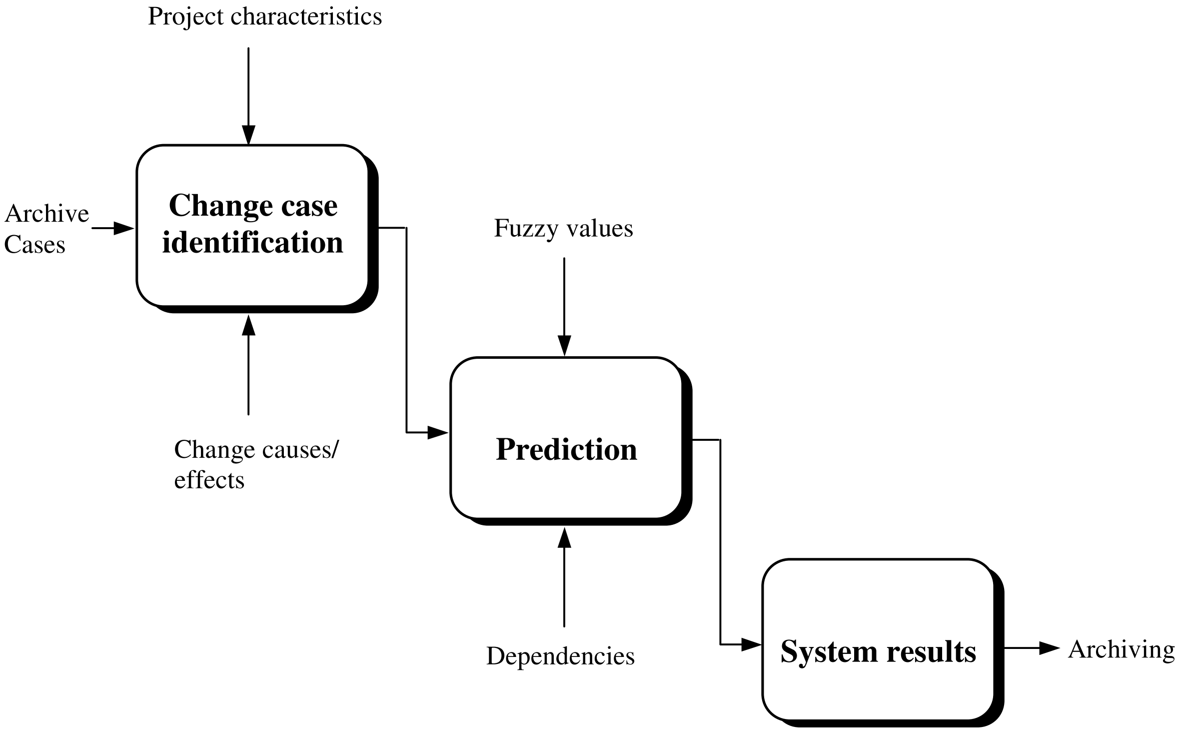

Figure 3. Information flow in the change prediction system

The initial input to the change case identification include; project characteristics, change causes and change effects (prediction elements). The project characteristics are categorized as External, Organisational and Project characteristics. The change effects are also categorized as direct effects and indirect effects. A query tag is designed to retrieve information on each set of elements from the database. Another query tag is designed to retrieve information on a change case from the case-base archive, if needed. The selected elements from the database are used to define dependencies within a change case. The relevant data is provided to subsequent functions. The next function activated by the user is to execute the fuzzy model. The prediction is based on fuzzy values allocated for the prediction elements by the user with the help of methods and algorithms developed for the system. Dependencies between the prediction elements are also defined by fuzzy values. The output of this function includes the likelihood of change occurrence and change effects on project parameters. The system output is displayed on interface frames. The last function, archiving, includes generating a case-base for the studied change case in addition to updating the prediction elements database, if required. The main elements of the archive are: actual cases & documentation, system results, user input, and graphical display of the prediction elements and relationships.

5 System use and specification

The system uses human reasoning as the axis through which the data can be accessed and applied. Thus it can help users with problem solving and decision making, so as to provide comprehensive use of intelligence knowledge. The following scenarios describe some of the user's interactions with the system interfaces:

- The user starts the application by connecting with the system database, which displays a list of prediction elements or archived cases via Java Database Connectivity (JDBC). JDBC is an industry standard for database-independent connectivity between the Java platform and a wide range of databases. The JDBC interface provides a call-level API (Application Programming Interface) for SL-based database (Structured Language) access.
- The user selects an element for the change case by clicking its name from the appropriate list. This action causes the application to build lists of elements for each specific change case. Appropriate Java Swing components are used to facilitate these actions.
- The user can add more elements, which are not included in the database, where applicable, to the studied change cases. The system has the capability either to update the original database by the additional elements or to save them only for this specific change case.
- For a new change case, system users can integrate the case base to obtain information regarding a similar change case together with related parameters and elements. This enables further estimation and analysis.
- Input data required for the fuzzy model include fuzzy weights for the selected project characteristics. The data also include fuzzy values for the sensitivity of a change cause occurrence to variations in the project characteristics and fuzzy values for the sensitivity of the change impact to variations in the change causes. The system provides instructions to help with entering these data.
- The user runs the fuzzy model program of change prediction and its impacts. The results are shown on special forms and the change case is analyzed, from which the whole case can be saved on the system archive and database. This saving is useful for the purpose of comparing the system outputs against the actual change case and for future knowledge reuse.

6 Conclusions

The focus of change management in construction used to cover the areas of the identification of the change process, the best practice of change implementation within a project, the evaluation of change effects on specific project parameters and IT systems for managing reactive changes and facilitating the co-ordination of design changes.

Modelling construction change should consider the link between these main elements: 1) project characteristics that lead to change 2) causes of change, 3) the likelihood of change occurrence, and 4) the change consequences. Relating multiple change causes to multiple change effects is a major role for modeling change in construction. This research aimed to identify and forecast potential changes and develop solutions before the change occurs. This paper has presented the system architecture of a proposed fuzzy model that attempts to estimate the likelihood of occurrence of a change event and predict the effect of change on project parameters using data that are realistic to obtain. The paper detailed the main components and functionalities of the system. The flow of information between the system functions was illustrated. The system uses a fuzzy model to relate the existence of project characteristics to the occurrence of change causes, and hence to determine the overall change impact on project parameters. The sensitivity of the project parameters to variations in project conditions can be assessed. The model is also useful for dealing with proactive changes by addressing the main project characteristics that have an influence on change causes. Further work is required to improve the accuracy of the model output.

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